Contract Title: Self-Adaptive Aeropropulsion Components – Enhancing Axial Compressor Performance

Contract No.: Contract No. N00014-87-K-0352 and Grant No. N00014-91-J-1575

Principal Investigator: Professor A.H. Epstein, MIT

ANNUAL LETTER REPORT FOR FY91

1. Technical Objectives

The principal technical objective of this work is to explore the use of active feedback stabilization to suppress the performance limiting instabilities endemic to jet engine compression systems known as rotating stall and surge. Previous work under ONR sponsorship has shown that these disturbances are the mature form of small amplitude travelling waves characteristic of turbomachinery, and that damping of the small amplitude waves prevents rotating stall.

A major theoretical conclusion of this work, backed by experimental data, is that the compressor acts as a fluid oscillator with the rotating stall regimes representing the eigenmodes of the system. Thus, it is important to understand both the details of the oscillator (the compressor) and its forcing functions (distortion and turbulent fluctuations). Almost nothing is currently known about the nature of turbulent fluctuations in a jet engine and their relationship to compressor stability since, prior to the concept of active compressor stabilization, there was little motivation to pursue these questions.

The work to date has been on low speed research compressors with uniform inflow and low turbulence levels. The main aim of the new work is to extend both theory and experiment to include wave detection and active compressor control in the presence of inlet distortion and high turbulence levels characteristic of actual aircraft installations. By reducing or eliminating many of the design compromises now made to accommodate compressor stall, this technology holds the promise of significantly improving the performance of military gas turbine propulsion systems, expanding the maneuvering envelope, and reducing aircraft gross takeoff weight by as much as 10%.

2. Technical Approach

The primary technical approach is to develop a theory of hydrodynamic stability in compressors which accounts for inlet distortion, to test that theory on low speed research compressors at MIT and on data provided by cooperating jet engine manufacturers, to develop control algorithms based on the hydrodynamic stability theory which can be used to actively stabilize a compressor with inlet distortion, and to test these algorithms on an actively controlled compressor rig at MIT. A second thread is to establish through measurement and modelling the disturbance structure and amplitude characteristic of operating jet engines, as these act as a background forcing function for the fluid oscillations in the compressor. The experimental part of this work is necessarily concentrated on small jet engines for cost reasons (at least initially). The approach is to take simultaneous time-resolved measurements throughout the engine and then correlate these measurements with an analytical model of disturbances within the engine. The work is carried out by an interdisciplinary team of controls and fluids faculty and students.

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3. Technical Accomplishments

We have been able to formulate an analytical model of rotating stall in the presence of inlet distortion and use this model to simulate the essential behavior of such situations. In particular, the model duplicates much of the behavior observed in experimental observations and explains such things as spatial modes travelling in opposite directions at different mode numbers, and the wandering of phases as though driven by noise. The full complexity of the problem has made itself clear and considerable work will be required (and is planned) to synthesize these results into a coherent description of compressor behavior and to incorporate this knowledge into feedback control laws.

The installation of a small gas turbine engine (supplied at no charge to this effort by Textron Lycoming) is approximately 6-8 months behind schedule due primarily to late delivery of the engine. This engine, which has been specially modified for the experiments at MIT, was originally to arrive in May of 1991 but is not now due until late January 1992. The installation is anticipated to be complete by May 1992. Preliminary measurements have been carried out on an unmodified Allison S250-C20 turboshaft engine, demonstrating the feasibility of the approach.

4. Significance of Accomplishments

Should the 20% improvement in operating range measured in this low speed research compressor be realizable in a multi-stage high speed gas turbine compressor, that may translate into a reduction of gross takeoff weight for a fighter aircraft of as much as 10%. Dramatic gains can also be realized for gas turbine ship propulsion.

Specifically to this year's activity, the preliminary analysis of the inlet distortion modelling indicates that it should be possible to actively control compressors with inlet distortion, a necessary step for the practical utilization of this technology, especially for advanced low observable aircraft. Furthermore, this work suggests that it may be possible to infer the structure of the inlet distortion directly from measurements of the low amplitude travelling waves in the compressor. This "spin-off" technology could greatly simplify instrumentation and testing of engines during aircraft and engine development as it could reduce or eliminate the requirements for special instrumentation in test vehicles.

5. Presentations and Publications

1. Paduano, J., Valavani, L., Epstein, A.H., Greitzer, E.M., "Modelling for Control of Rotating Stall," 29th IEEE Conference on Decision and Control, Honolulu, HI, December 1990.

2. Epstein, A.H., "Rethinking Aerospace Sciences, A Coming Revolution in Active Controls," invited special event lecture, 29th AIAA Aerospace Sciences Meeting, Reno, NV, January 1991.

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3. Paduano, J., Epstein, A.H., Valavani, L., Longley, J.P., Greitzer, E.M., and Guenette, G.R., "Active Control of Rotating Stall in a Low Speed Axial Compressor," ASME paper 91-GT-88, presented at 1991 ASME Gas Turbine Conference, Orlando, FL, June 1991; to be published in *ASME Journal of Turbomachinery.*

4. Paduano, J., Valavani, L., Epstein, A.H., "Parameter Identification of Compressor Dynamics During Closed Loop Operation," *Proceedings of the American Control Conference*, Boston, MA, June 1991.

Other Presentations

"Active Compressor Stabilization", Wright Laboratories, Wright Patterson AFB, OH, December 1990.
"Active Compressor Stabilization", Allison Gas Turbines, Indianapolis, IN, November 1991.
"Smart Engines," National Academy of Engineering, ASEB, Irvine, CA, January 1991.
"Active Control of Compressor Instabilities," The Kelvin Club, Cambridge University, May 1991.
"Active Control of Compressor Instabilities," Beijing Institute of Aeronautics and Astronautics, October 1991.
"Active Compressor Stabilization", Textron Lycoming, February 1991.

6. Participants

Professor A.H. Epstein	Principal Investigator
Professor E.M. Greitzer	Co-Investigator
Professor L. Valavani	Co-Investigator
Dr. G.R. Guenette	Co-Investigator
C. Boussios	SM anticipated June 1992
J. Paduano	Ph.D degree awarded December 1991
Professor F. Marble (Caltech)	Consultant